Heat Treatment and Tension Curves in Contemporary Steel Materials Monitored by Acoustic Emission

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Abstract. Heat treatments between RT and 1100°C and tensile tests were carried out parallel using a Gleeble 3800 thermo-mechanical simulator in weldable structural steel (S235JRG2), TRIP steel and heat resistant bainitic steel (15Ch2MFA). Acoustic emission (AE) sensors were applied to monitor acoustic events along the samples under investigation including amplitudes, rate of hits and localization of AE events. Increase of rate of hits of AE was observed in phase transition at temperatures corresponding to austenite-ferrite and ferrite-bainite transitions. High amplitudes observed during heat treatments were dropped more than to half when tension started.

Specific amplitudes were observed during high temperature tensile tests with growing amplitude after the start of contraction, showing that amplitudes of AE are inverse proportional to applied force.

It was proven that acoustic events were generated partly and mainly by magnetic forces caused by heating with alternating strong current, similarly to Barkhausen effect, in TRIP steels and baintic steel (15Ch2MFA). This opened the possibility for permanent acoustic monitoring of ferromagnetic steels.

Introduction

In the early 1950 J. Kaiser investigated the emission of audible sound from the materials subjected to external loads [1]. It is regarded as the beginning of application of Acoustic Emission (AE) technique for material characterization. In spite the fact that the beginning was connected to stresses inside the material, technical limitation did not made that time to use it for investigation of the inner structural quality and phase transition in the materials. For a long time AE was used mainly for vessel integrity tests or large construction testing finding the weak points, mainly to find starting of cracks. Reading excellent review paper of Kanji Ono on Acoustic Emission in Material Research [2] it becomes clear that he could hardly find nine papers on phase transition section, six publication for fatigue testing in 2011. Since that the number of publication is rapidly growing. This is due to the fact that today AE technique has developed we can really sample the signal up to 10 MHz or higher recording the signal itself while earlier only analogue technique made possible to estimate the most important AE parameters (like starting time, magnitude, Duration, rise time, count rate etc.) Fourier spectra and more like wavelet decomposition made possible to analyze the fast changing signal.

We investigated different materials in our Gleeble 3800 thermo-mechanical simulator with the main aim of material research, getting material parameters. The Acoustic Emission (AE) monitoring going parallel with those investigation was carried out as additional tool for getting deeper insight into processes. We shall see we have got very interesting results during high temperature tensile tests.

Instrumentation

Experiments were carried out in our Gleeble 3800 termo-mechanical simulator [3] (Fig1.).

Fig. 1. Gleeble 3800 thermo-mechanical simulator with an open experimental box.

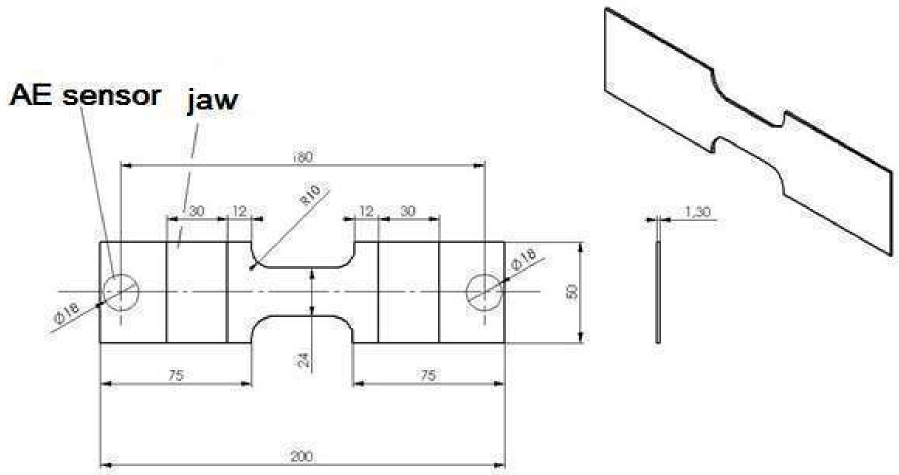

Fig. 2. One of the slim samples (TRIP steel), the place of the sensors and jaws marked

Our AE sensors were Sensophone A-15AM type with 150MHz resonance. Measurements were carried out using AED-40/32 type AE system produced by Geréb&tsa [4]. 1D localization program is a built in service of that system.

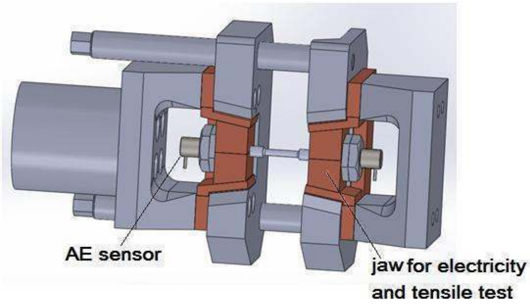

Fig. 3. Another type of samples (15H2MFA or S235JRG2) in the experimental box of the simulator

Acoustic Events During Heat Transients

AE during heat treatment of TRIP steel samples

An experiment was set up for the Transition Induced Plasticity (TRIP) steel sample. It was heated up to 950°C then holding at that temperature for two minutes the sample was cooled down. Having two sensors on the ends of the sample we were able to localize the source position of each AE burst.

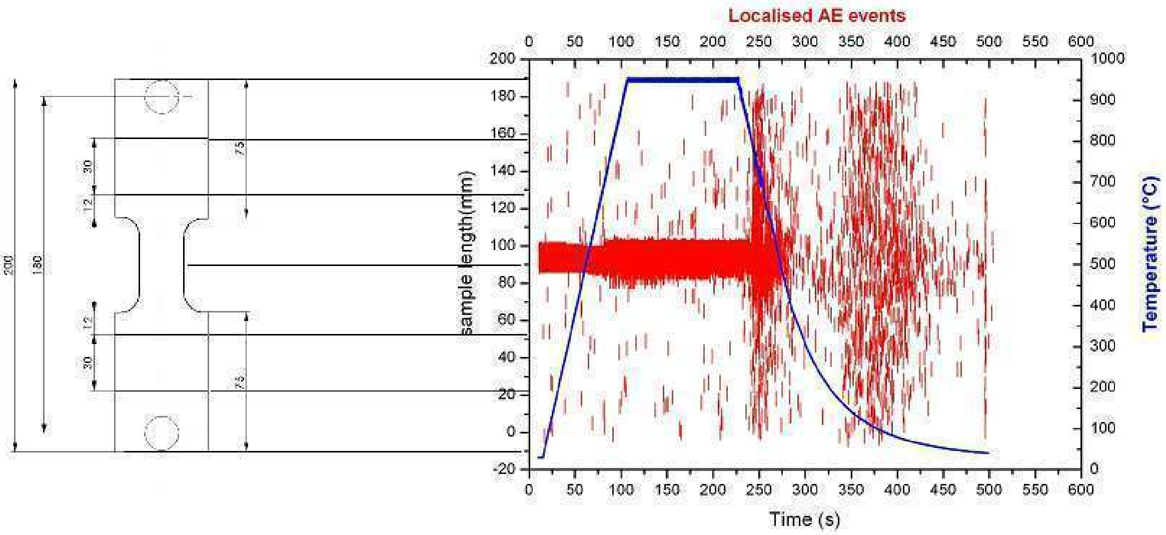

Fig. 4. Flat TRIP steel sample and AE events localized along the sample (red) exhibit two bunches of AE events at 767^{o}C and at low temperature

From figures 4 and 5 we can conclude that the first bunch of AE all along the samples appeared at austenite-ferrite transformation between 800-700^{o}C. We have to understand that the temperature of the sample is the highest in the middle and cooling comes from the two ends. The second wider bunch of AE events cannot be explained by be explained by bainite martenzitic transformation, however, figure 5 does not confirm this statement.

Triple heating and consecutive tensile test in S235JRG2 steel

AE measurements were carried out during triple heating and cooling of a cylindrical sample with a consecutive tensile test after the last cooling, but still at elevated temperature at 400^{o}C. The temperature conditions are shown on Fig.6. While the heating rate was the same in all three heating treatments (10^{o}C/sec) and we kept the heated sample at high temperature (1100^{o}C) for 60 sec in all three cases, the cooling velocity was changed as:

5°C/sec, 10°C/sec and 39°C/sec. Each time we cooled down the sample until 400°C, which is well below the austenite bainite transition temperature.

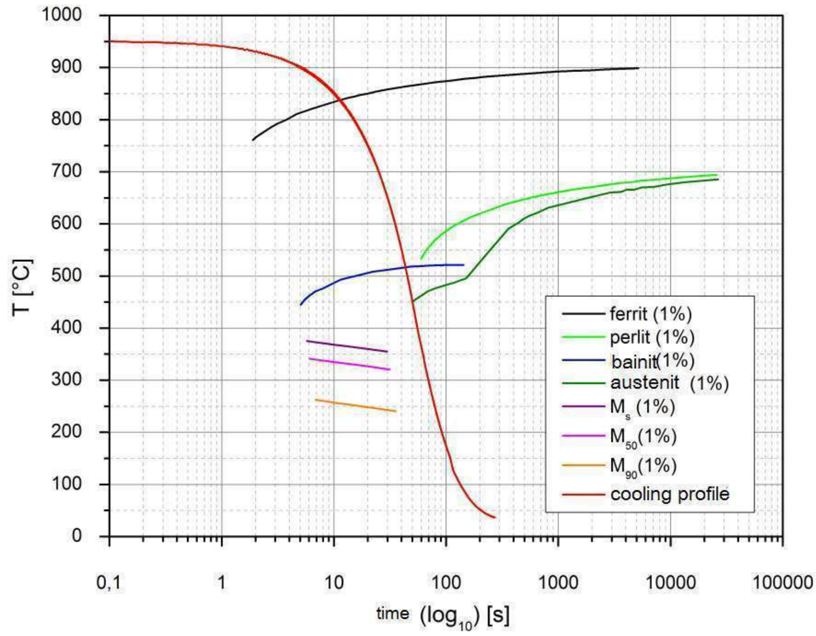

Fig. 5. Cooling profile of the experiment with corresponding ferrite, bainite and perlit contents

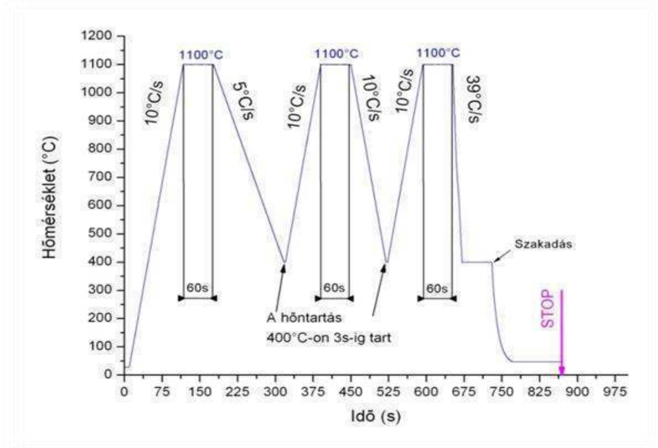

Fig. 6. The heating-cooling profiles with breaking the sample at the end

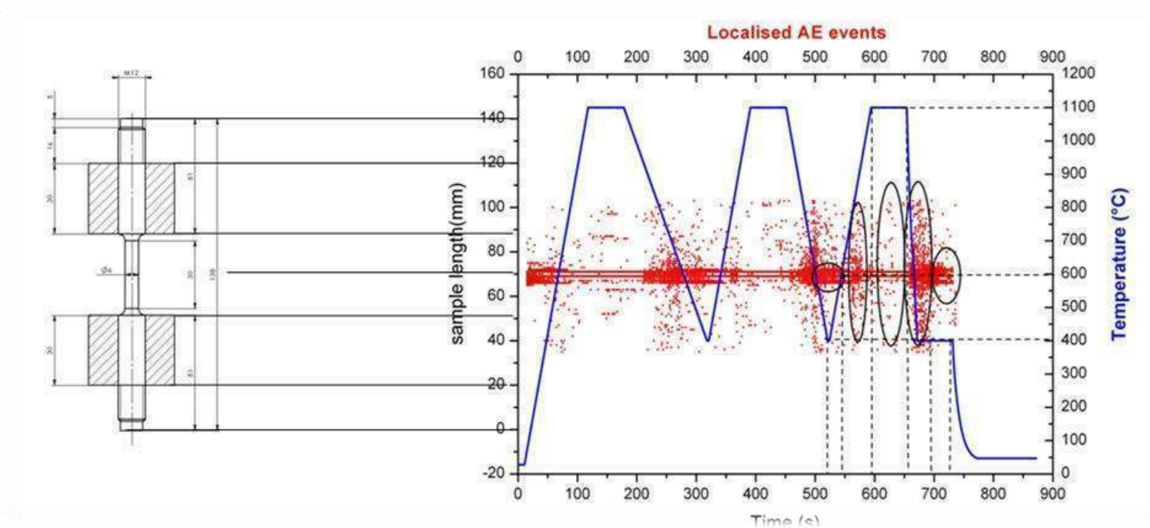

Fig. 7. Localized ABE events during the heat treatment and final break of the sample

On figure 7. the temperature changes are shown with blue line together with detected and localized acoustic emission events. It can be seen, that during the first heating there are ABE events mainly only in the test section of the sample. Also during all three high temperature holding there were ABE events only in that central segment. We understood from the second section of this paper that this was due to Barkhausen noise caused by the magnetic field due to high heating current. When cooling starts the number of ABE events growth. But there are other AE events appearing also just as the cooling crosses 700^{o}C. Those are due to phase transitions. The faster the cooling (in the second and third steps) the more AE are detected and even their source places are more and more distributed along the samples. It is also very remarkable that during the second and even more during the third heating period there were also more and more ABEs. The best explanations for distributed ABE is the phase transition from austenite to bainite during fast cooling and also phase transition to austenite during the second and third cooling.

Acoustic Barkhausen Events

We noticed, and this was demonstrated in details, that there are too many AE events detected from the sample, even during simple heating, without tensile and without change of temperature. The reason for that became obvious only in another experiment, where low cycle fatigue test was carried out and not only the conventional AE parameters were fixed by the conventional AE system, but the total AE time signals were recorded using a sampling system developed by us. More details you can find in the paper [ ] presented also in this proceedings. Here we reproduce only a fragment of that time signal (see Fig.8.). From that it is obvious that the tremendous amount of bursts consists of a periodical uniform bust train with repetition time of 10msec due, which appear due to 50Hz frequency of the heating AC current. From the detailed analysis it became clear, that in the section, where the cross section of the sample is the smallest the current was enough to produce magnetic field up to 0.4 T, which is quite enough to produce Barkhausen effect, which can be detected also using acoustic sensors due to so called Acoustic Barkhausen Event (ABE).

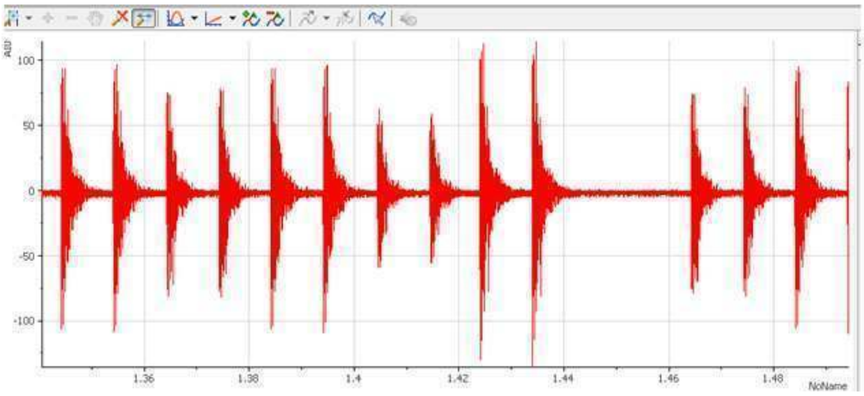

Fig. 8. Bursts standing 10msec from each other proves they are connected to 50Hz alternating heating current

However, it is also important to notice that the magnitude of ABE (or typically the RMS value which is measured in the literature) depends upon the internal stresses of the magnetic materials.

Results Measured In 15H2MFA Steel

These experiments were carried out on a cylindrical sample (cf. Fig.3) made from ferritic 15H2MFA steel, which is the structural material for VVER-440 type nuclear power plant reactor vessels. The temperature was first raised to 265oC (which is a typical operating temperature of the reactor wall), and kept for more than 100 sec at that temperature, then a normal tensile test was carried out at that temperature (see Fig.9 blue line for temperature green line the applied force). The red line shows the rate of the hit measured by AED-40 system using AE sensor on one end. It is clear; that there is a rather high rate of hit during heating process, and it does not depends on temperature. This is ABE due to constant heating current. When the tensile test starts it drops. It is a well know effect published in several paper (see cf. Meszaros et al [5]), that the amplitude and RMS of ABE burst depends on the internal stresses. When stress growths the amplitude drops (since we have a threshold several hits are lost due to the reduced amplitude). Remarkable, that the rate of the hits follows the force line. But that is not a direct connection. At the beginning, when the applied force begins, there is a sudden drop in the rate, and then the rate grows with the force and declines with the force. However, there are different mechanisms behind the first part of the changing force during the elasticity and behind the falling force and rate of the hits.

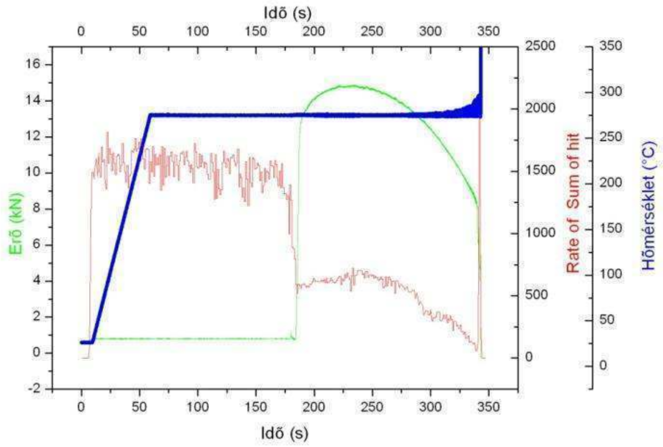

Fig. 9. Force-Rate of hit curve (blue line the temperature, green line the force)

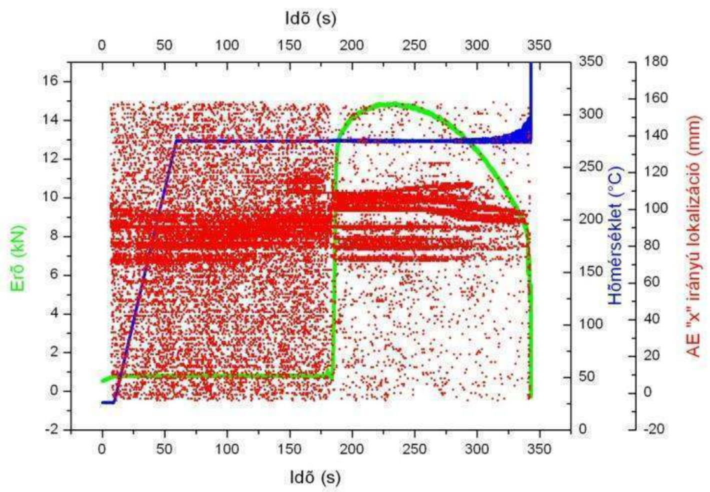

Fig.10. Localization of the source of ABE along the sample (red dots) with temperature curve (navy blue) and change of the force (green line)

This becomes partly clear from Figs 10 and 11. It is seen, that the amplitude and even the source are distributed along the whole sample during heating. There are some concentration in the middle, but this is due to temperature distribution and due to the fact that the sample is narrower here. When the tensile test starts events are concentrated much more to the central part and the almost evenly distributed amplitude (Fig.11) becomes not only much smaller (then 70dB), but also there are certain amplitudes with high priority. This is a very new observation. These stripes in the right hand side of Fig.11. seems to follow the reciprocate of the force line, which had been observed earlier in magnetic Barkhausen noise. They noted this for RMS value of the Barkhausen noise, therefore for the fullness of information we present here also the change of the MARSE (Measured Area Of The Rectified Signal Envelop) on Fig.12

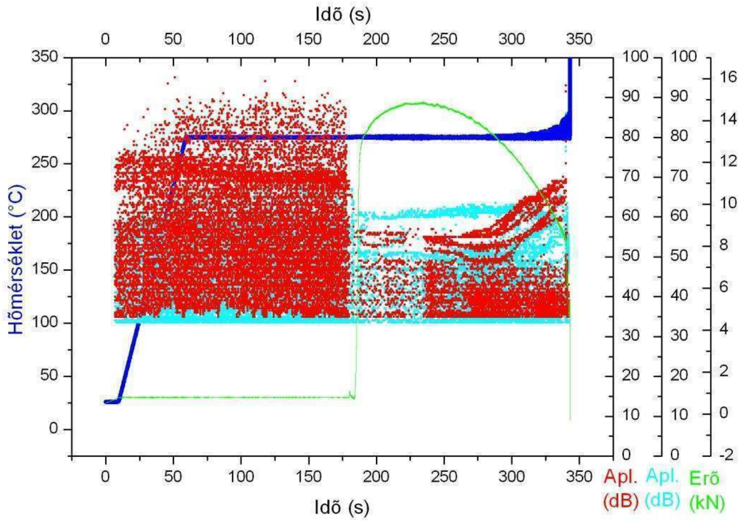

Fig.11 Amplitude of AE hits (red and light blue dots) /navy blue line-temperature, green line –force/

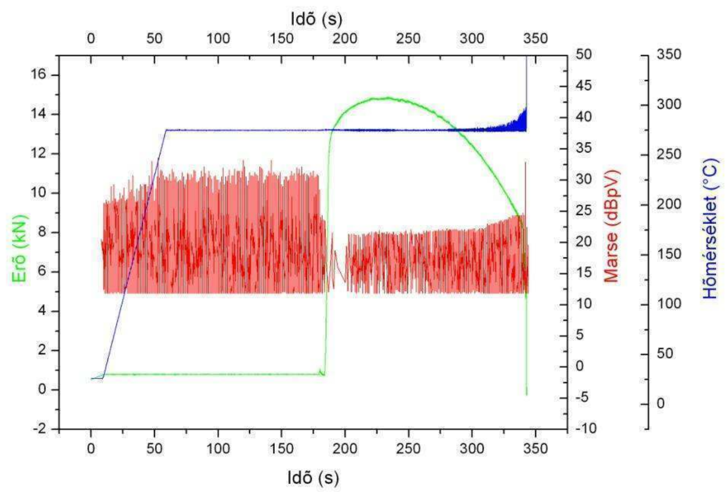

Fig.12. Change of the MARSE (Measured Area Of The Rectified Signal Envelop) during the experiment

Conclusion

Our experimental results proved that phase transition in steels investigated can be monitored using AE sensors. At least we found a bunch of AE events just at the temperature of phase transition during cooling period. Experiments were disturbed by acoustic Barkhausen events producing very many burst in the middle of the sample where the AC and consequently the magnetic field in the material was the strongest.

However, we could observe such Acoustic Barkhausen Event (ABE), in more ferritic steels (e.g. 15H2MFA), where they exhibited also very interesting signature due to change of the internal stress during high temperature tensile test. It was obvious, that the magnitude (and consequently the RMS) of ABE dropped with growing tensile stresses, which is in good agreement with earlier publications in Magnetic Barkhausen Noises. It is obvious that acoustic Barkhausen events could be use for monitoring internal stresses in the ferritic steels.
An advantage of ABE in comparison with traditional Barkhausen noise, that sensor can hear the acoustic noise from a long distance and meanwhile we can still localize the source of the event, consequently it also becomes possible to say, where the stresses grow and where they decrease. In comparison with AE, ABE is an active non-destructive event, we can generate ABE but we cannot generate AE. This opens new possibilities to use ABE method in industry where difficult to access.

Acknowledgements

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